Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-541
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 4 October 2017

Influence of geomagnetic activity on mesopause temperature over Yakutia

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Abstract. The long-term temperature changes of the mesopause region at the hydroxyl molecule OH (6-2) nighttime height and its connection with the geomagnetic activity during the 23rd and beginning 24th solar cycles are presented. Measurements were conducted with an infrared digital spectrograph at the Maimaga station (63°N, 129.5°E). The hydroxyl rotational temperature (TOH) is assumed to be equal to the neutral atmosphere temperature at altitude of ~87 km. The average temperatures obtained for the period 1999 to 2015 are considered. The season of observations starts at the beginning of August and lasts until the middle of May. The maximum of the seasonally averaged temperatures is delayed by 2 years relative to the maximum of flux of radio emission from the Sun with a wavelength of 10.7 cm, and correlates with a change in geomagnetic activity. Ap-index as a measure of geomagnetic activity is taken. Temperature grouping in accordance with the geomagnetic activity level showed that in years with high activity (Ap> 8), the mesopause temperature from October to February is about ·10 K higher than in years with low activity (Ap <= 8). Cross-correlation analysis showed no temporal shift between geomagnetic activity and temperature. The correlation coefficient is equal 0.51 ± 0.1 at 95% confidence level.

Introduction

Long-term changes in the state of the mesopause, such as the linear trend and the fluctuations associated with the 11-year cycle of changes in solar activity, are investigated by different methods. In the review Beig et al. (2008) show that, according to numerous studies, the response of the mesosphere/low thermosphere temperature to the change in solar activity reaches 4-5 K / 100SFU, where SFU is the solar radio flux at a wavelength of 10.7 cm in 10^{-22} W M^{-2} Hz^{-1}. Tang et al. (2016) estimated the change in the temperature of the mesopause from 2002 to 2015 using the measurements of the SABER radiometer installed on the TIMED satellite. They showed that the average global response is about 5 K / 100 SFU, which does not contradict the results given in the review of Beig et al. (2008). The response of the temperature to the change in the flux of radio emission F10.7 at high latitudes is greater than at the middle latitudes and reaches up to 7-10 K / 100SFU.

Previously, according to data obtained from 1997 to 2000 at the Maimaga station, we found the temperature response equal to 11 K / 100SFU (Gavrilyeva and Ammosov, 2002). Further, Ammosov et al. (2014) presented the results of data analysis obtained in a time interval comparable to the solar cycle duration from 1999 to 2013. Analysis showed that the temperature change follows the solar activity change with 25 months delay. The temperature response at the delay of 25 months reaches 7 K/100 SFU.

It is known that the geomagnetic activity maximum lags behind the solar radiation maximum including the index F10.7. As a measure of geomagnetic activity widely available index Ap was used. Both indexes were acquired from the National Geophysical Data Center, NGDC (ftp://ftp.ngdc.noaa.gov/STP). The radio emission flux F10.7 and Ap-index of magnetic disturbance changes over the last 4 cycles of solar activity is shown in Figure 1. As can be seen from the Figure 1, Ap-index changes follow the F10.7 changes with a lag of 2-3 years. Therefore, it was logical to assume that the long-term temperature fluctuation of the subauroral mesopause correlates with the change in geomagnetic activity.

The purpose of this paper is to investigate the connection between the geomagnetic activity change (Ap-index) and the OH rotational temperature based on night measurements obtained for the period August 1999 to May 2015.

Instrumentation and measurement technique

Mesopause is the atmosphere region where the mesosphere borders on a thermosphere (80-100 km) and a temperature minimum is located. The radiating layer of excited hydroxyl (OH) is located at about 87 km in mesopause region.

The activated hydroxyl molecule commits $2 \cdot 10^4$ s^{-1} collisions before radiation, which is sufficient for thermalization with the surrounding medium. Therefore, the OH rotational temperature calculated from the night sky spectra indicate the neutral atmosphere temperature at the radiation height (Khomich et al., 2008).

The OH(6-2) rotational temperature data (TOH) for the presented paper were obtained with the infrared spectrograph (Ammosov and Gavrilyeva, 2000). The spectrograph was installed at the optical station Maimaga (63° N, 129.5° E) which is located at a distance of about 120 km to the north of Yakutsk. Observations were carried out in cloudless nights, with the sun at least 9° below the horizon. For the analysis the data obtained during moonless time and in the absence of aurora were selected. The location of the observation station makes it possible to perform measurements only from the beginning of August to the middle of May since the summer mesopause is constantly sunlit at the Maimaga latitude.

The method for estimating the rotational temperature of molecular emissions is based on the least squares fit of model spectra constructed with regard to the instrument function for different previously specified temperatures to an actually measured spectrum (Ammosov and Gavrilyeva, 2000). The model spectrum whose deviation from the actual one is less than the registration noise is considered to correspond most closely to the reality; and the rotational temperature determined based on this spectrum corresponds to the temperature at the mesopause height. The estimates indicate that random errors in temperature measurements vary from 2 to 10 K depending on the signal-to-noise ratio. As the estimations show the errors of temperature measuring are in the range of 2–5 K depending on the signal-to-noise ratio level. Since different published transition probabilities lead to temperature differences up to 12 K (Turnbull and Lowe, 1989; Greet et al., 1998) all the data are analyzed using the same Einstein coefficients by Mies (1974), for consistency.

Results

The rotational temperature data set comprises 2864 nightly average temperatures obtained from August 1999 to May 2015. The measurements of the nightglow spectrum are conducted from the beginning of August to the beginning of May. The longest night data series are registered in the winter. The number of measurements per month varies from 10 to 25 nights. The TOH and F10.7 index average values for the measurement season (from August to May) for 1999-2015 are plotted in Figure 2a. The TOH and Ap-index mean values variations are shown in Figure 2b. The average values of the F10.7 index and Ap-index were calculated in the days that coincided with the TOH measurements at the Maimaga station. As can be seen from the Figure 2, the TOH inter annual variation is delayed relative to the F10.7 change and is more consistent with the Ap-index variation. The correlation coefficient of TOH and Ap-index is equal 0.51 ± 0.1 at 95% confidence level.

The night temperature means were divided into two groups for further analysis. First group includes the measurements which were conducted at the season with high geomagnetic activity when average Ap-index > 8. Second group consists of night TOH measured during the season with Ap-index <= 8. The number of observations per month in two groups is shown in Figure 3. The seasonal distribution of measurements is approximately the similar. A monthly mean TOH in geomagnetic active years (Ap> 8) and in geomagnetic quiet years (Ap <= 8) are plotted in Figure 4. The mesopause temperature from October to February is higher in the geomagnetic active years in comparison with the geomagnetic quiet years. There is no dependence of the TOH on the level of geomagnetic activity in autumn and spring. However, it should be noted that at this period the number of observations is not large.

Discussion

In the last decade, many papers have been published which were devoted to the study of the atmosphere response to the proton and electron fluxes with various energies. Model calculations showed that particle precipitations through a cascade of dissociation, ionization and recombination processes create nitrogen (NOx) and hydrogen (HOx) oxides in the high latitude thermosphere and mesosphere. HOx is relatively short-lived (of the order of days) leading mostly to local effects, while NOx can lead to both short and long term (order of months) catalytic ozone destruction in the middle atmosphere (Krivolutsky et al., 2006, Baumgaertner et al., 2009, 2011). Observations from satellites show that energetic particles precipitation change the nitrogen oxides amount in the atmosphere. Randall et al. (2007) investigated the energetic particles precipitation effect on the southern hemisphere stratosphere from satellites measurements for the period 1992 to 2005. It was shown that the amount of NOx produced by the energetic particles precipitation corresponds to the level of geomagnetic activity. Baumgaertner et al. (2009, 2011) used the atmospheric chemistry general circulation model ECHAM5/MESSy to simulate polar air temperature effects of geomagnetic activity variations. The researchers calculated NOx fluxes formed by low-energy electrons precipitations using the average annual Ap from 1991 to 2005. Model average annual NOx concentrations were compared with the nitrogen oxides concentrations computed by Randall et al., (2007) from HALOE radiometer measurements on board the UARS satellite. The measured and model average annual concentrations of nitrogen oxides are almost identical (see Figure 1. in Baumgaertner et al., 2009). Thus, the authors have convincingly demonstrated that the electron precipitations can be the sources of nitrogen and hydrogen oxides in the upper and middle atmosphere. In the further paper of Baumgaertner et al. (2011) showed that, strong geomagnetic activity and the associated NOx enhancements lead to polar stratospheric ozone loss. Compared with the simulation with weak geomagnetic activity, the ozone loss causes a decrease in ozone radiative cooling and thus a temperature increase in the polar winter mesosphere. (Figure 9 in Baumgaertner et al., 2011). A similar effect of the ozone loss due to energetic particles precipitation on the atmosphere temperature and dynamics in other models has been obtained (Semenuk et al., 2011, Karami et al., 2015, Arsenovic et al., 2016,). There is a publication series (Lu et al., 2008, Sëppala et al., 2009, Seppala et al., 2013), where the authors investigated the geomagnetic activity effect in the atmosphere based on the meteorological measurements ERA-40 and ERA interim data set. The authors studied the atmosphere climatology from 1000 hPa to 1 hPa separately in the years with high and low geomagnetic activity. They found that high geomagnetic activity can drive a strengthening of the Northern Hemisphere polar vortex, with warming in the polar upper stratosphere and cooling below. Meteorological data analysis shows that the upper stratosphere warming starts in beginning of December and lasts until March (Sëppala et al., 2013). The heating descends downwards during winter. Karami et al. (2015) investigated the thermal and dynamic response of the middle atmosphere to ozone concentration losses due to energetic particles precipitation using the chemistry–climate general circulation model EMAC. The results of simulations show that as winter progresses the temperature anomaly move downward with time from the mesosphere/upper stratosphere to the lower stratosphere.

The temperature difference in the geomagnetic active years in comparison with the geomagnetic quiet years has been observed since October to February in our measurements. It should be noted that model and experimental researches of meteorological parameters are limited to a height of 80 km. The hydroxyl radiating layer is located in the mesopause region (~ 87 km). Therefore, warming in our measurements has to be detected earlier. The energetic particles precipitation change temperature and dynamics in the winter polar atmosphere as shown in the above studies. Most of the measurement of the mesopause region temperature at our latitude is also carried out in the winter. Figure 5 shows the F10.7 and Ap-index averages variations in January from 1975 to 2016. The regular measurements of the mesopause region temperature began approximately in these years. Unlike the previous solar cycles, it is clearly seen that F10.7 maximum leads Ap-index maximum by about 2-3 years in the 23rd solar cycle. It should be noted, that in our research the influence of the solar irradiance and the long-term linear trend on the mesopause temperature is not studied. In order to separate correctly the influence of these components, the data of several solar cycles is necessary.

The energetic particles precipitation can have a direct effect on the mesopause region temperature and dynamics. von Savigny et al., (2007) observed a severe decrease in the noctilucent clouds occurrence rate in the southern polar mesopause region made with SCIAMACHY on Envisat satellite immediately after the onset of the enhanced solar particle precipitation on January 16, 2005. At the same time, the atmosphere temperature increase at an altitude of 85 km are employed with the MLS on AURA. Temperature measurement with the MLS on AURA during the proton event on November 7-10, 2004 showed the polar mesosphere temperature increase by 5-10 K while the polar stratosphere temperature decreased (Hocke, 2017). However, other researches showed that there may be another indirect mechanism. Dynamical interaction between the mean flow and planetary waves in the stratosphere play an important role in transferring the geomagnetic activity induced effects (Arsenovic et al., 2016, Seppala et al., 2013, Karami et al., 2016).

Conclusions

The data set of the hydroxyl emission airglow comprises 2864 nightly average temperature values obtained from August 1999 to May 2015 at the Maimaga station are considered. The measurements of rotational temperature of OH(6-2) at Maimaga subauroral station for the August 1999 to May 2015 period were studied in search for geomagnetic activity effect. Correlation between seasonally averaged TOH and geomagnetic activity index Ap is statistically significant and is equal to 0.51.

The winter polar mesopause approximately 10K warmer in the years with high geomagnetic activity (Ap>8), than in the years with low geomagnetic activity (Ap<=8). Warming of the mesopause starts in October and lasts until February, which is about 1-2 months earlier than the warming in the stratosphere. It can be explained by altitude difference between mesopause (87 km) and 1 hPa (50 km) level where the onset of warming was noticed (Sëppala et al., 2013). Warming signal moves down from high altitude to low one. Thus, measurements of the mesopause temperature revealed the mesopause region heating in geomagnetic active periods for the first time.

Acknowledgments.

The reported study was funded by RFBR according to the research projects No. 17-05-00855 A, 15-05-05320 A.

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Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-541
Manuscript under review for journal Atmos. Chem. Phys.
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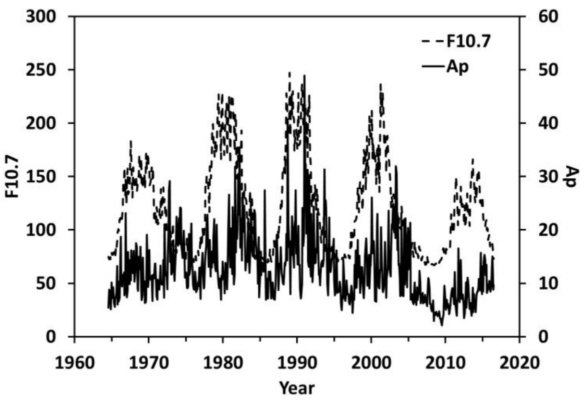

Figure1: Monthly mean F10.7 and Ap for 1965-2016. Both indexes were acquired from the National Geophysical Data Center, NGDC (ftp://ftp.ngdc.noaa.gov/STP).

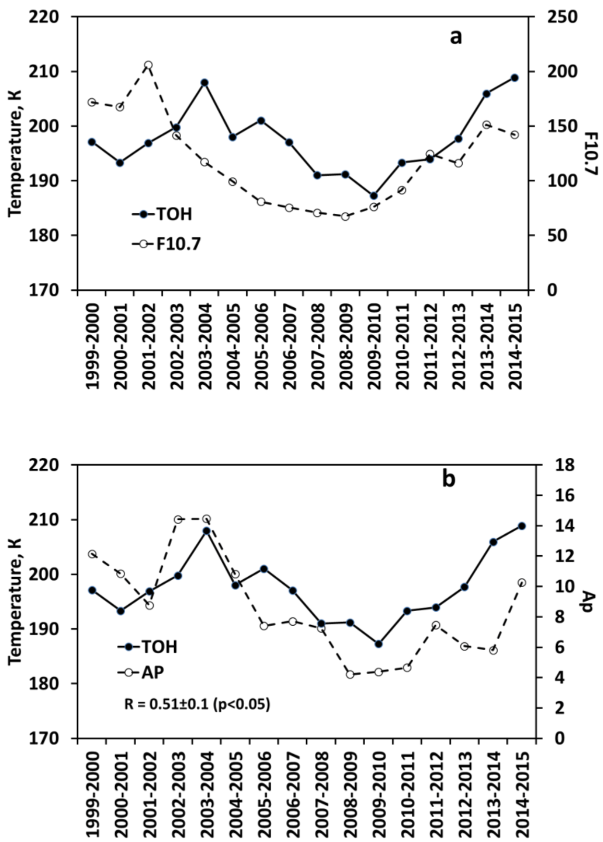

Figure 2: (a) Seasonally averaged TOH and F10.7 index (from August to May) for 1999-2015. (b) The TOH and Ap-index mean values for 1999-2015. The average values of the F10.7 index and Ap-index were calculated in the days that coincided with the TOH measurements at the Maimaga station.

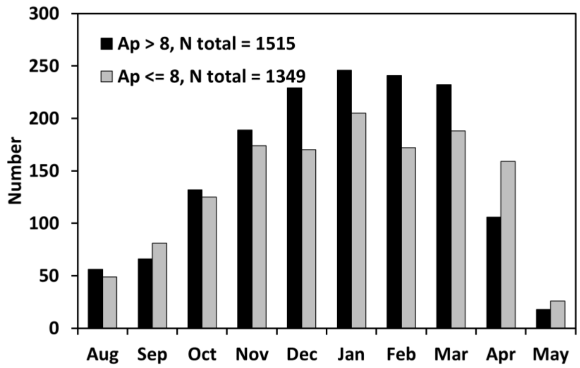

Figure 3: The number of measurements per month during the geomagnetic activity years (Ap > 8) – black columns, grey columns – the monthly distribution of measurements during geomagnetic quiet years (Ap <= 8).

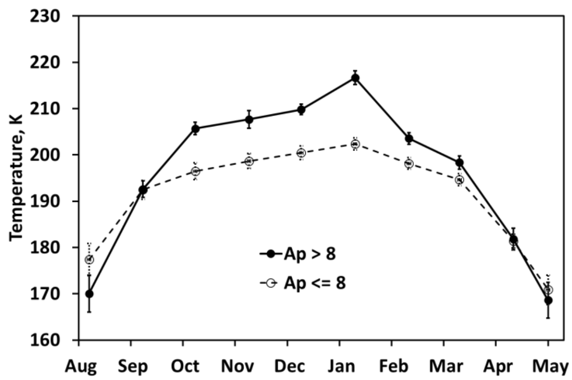

Figure 4: A monthly mean TOH in geomagnetic active years (Ap> 8) and in geomagnetic quiet years (Ap ≤ 8). Vertical bars correspond the standard deviations.

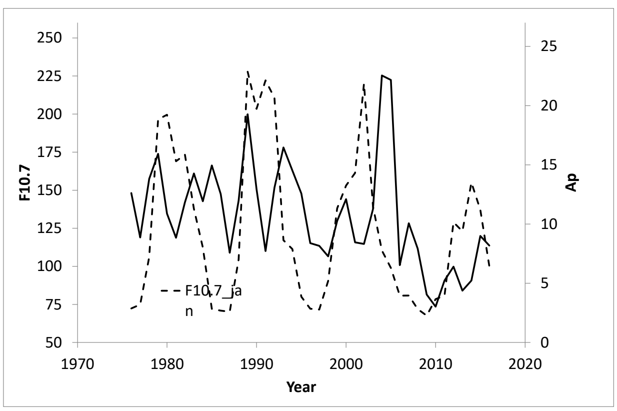

Figure 5: The F10.7 and Ap-index averages variations in January from 1975 to 2016.